Ring beam dynamics studies update

- Effect of impedance offset does not lead to instability but leads to significant emittance growth ("bana-shape" effect).
- Non-linear field of sextupoles lead to some emittance growth. This effect is negligible compared to the space-charge induced growth.
- Effect of high-order coherent resonances on space-charge limit in the SNS.
- Application of envelope instability to circular machines.
- Transverse instability due to impedance.
- Various stabilization mechanisms of collective instability.
- Resonance bandwidth, tolerable error and corrections.

Transverse beam instability in the SNS due to the extraction-kickers impedance

- Fedotov, M. Blaskiewicz, J. Wei (BNL) S. Danilov, J. Holmes, A. Shishlo (ORNL)

May 14, 2002

Acknowledgment

We thank D. Davino, N. Malitsky, Y.Y. Lee and

N. Tsoupas and AP groups for many useful discussions.

Numerical implementation

- In order to study collective beam dynamics, computational models for the impedance and 3D space charge have been developed and implemented in ORBIT (S.Danilov,J.Holmes,J. Galambos)
- After these new algorithms were successfully benchmarked they were implemented in UAL (A. Shishlo)
- These new models allow us comprehensive study of collective beam dynamics

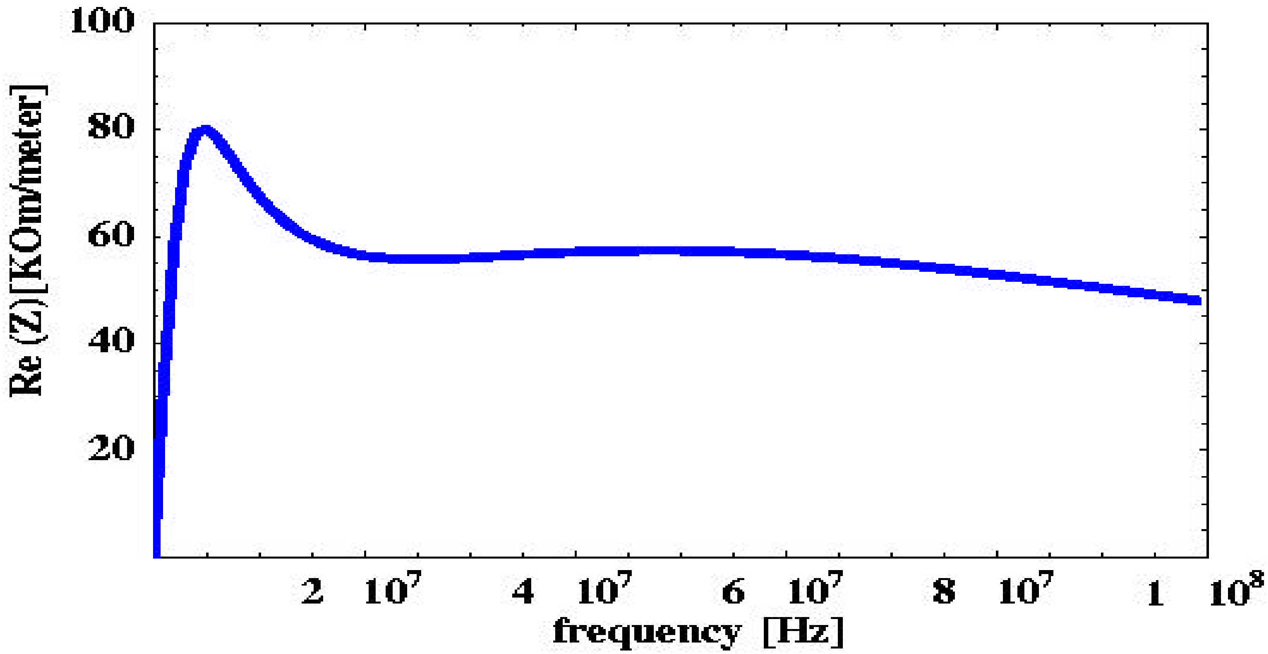
Simulations

- **Preliminary studies with full-intensity beams indicated that 2MW SNS beam is near the instability threshold (S. Danilov, J. Homes, M. Blaskiewicz)**
- **We then proceeded with realistic multi-turn injection scenario.**
- **In order to avoid numerical diffusion with the 3D space charge model we first obtained saturation of numerical parameters.**
- **This resulted in implementation of the code on BNL/ITD parallel cluster (up to 40 CPU) which allowed this time consuming calculations (N. Malitsky)**
- **Presented here simulations are done with half a million particles on 20 CPU.**
- **Important feature of instability thresholds with 1060-turn injection is the fact that final intensity is reached only at the end of accumulation right before the extraction.**

Impedance model

- **Recent measurements of the transverse coupling impedance of one full-size model of the 14 extraction kickers led to the realistic estimate of this impedance contribution (D. Davino and H. Hahn)**
- **This impedance was significantly reduced with the 25 W termination.**
- **All 14 kickers are represented by a single impedance node using the average beta-function approach.**
- **Such approach overestimates magnitude of the impedance by approximately 15%. As a result, our threshold estimates are slightly conservative.**

Re(Z) for full 14-kicker system



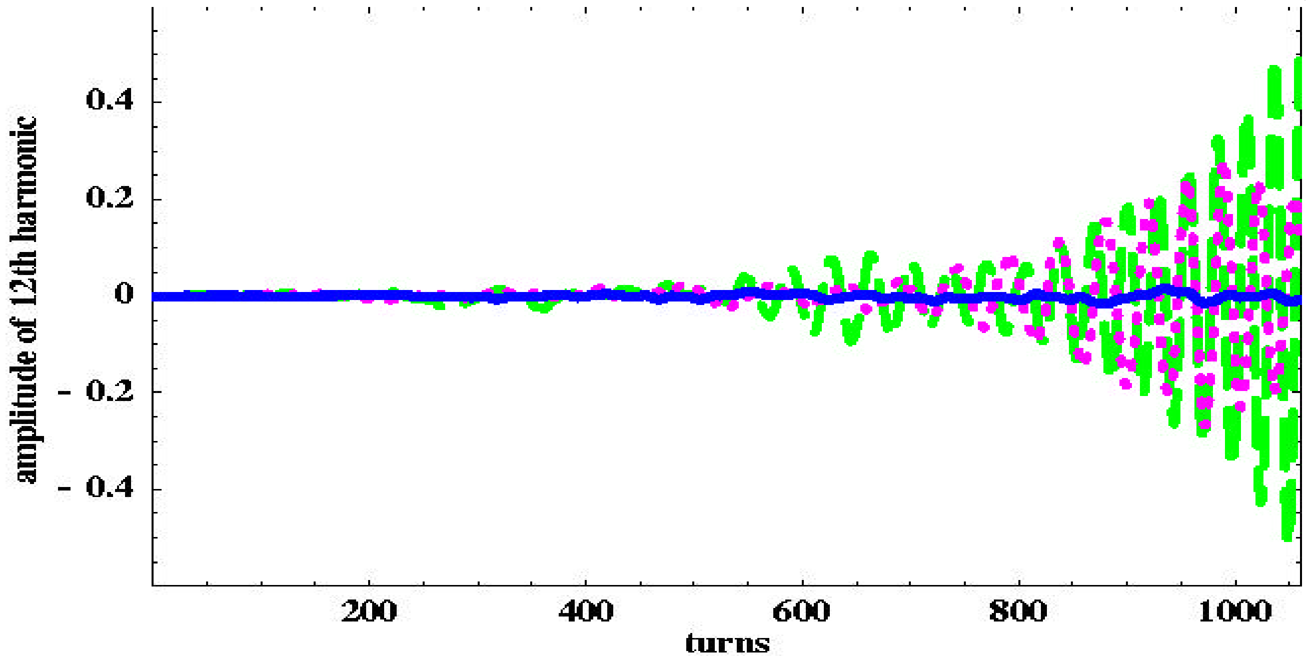
Impedance model used in simulations

Outline

- Instability thresholds

- Study topics:
- Open vs 25 W termination impedance
- Low frequency (1-2 MHz) and space charge stabilization
- Stabilization with b/a (effective tune spread along the bunch due to longitudinal current density)
- Small b/a , quadrupole effect

N=2.0*10^14 at the end of accumulation

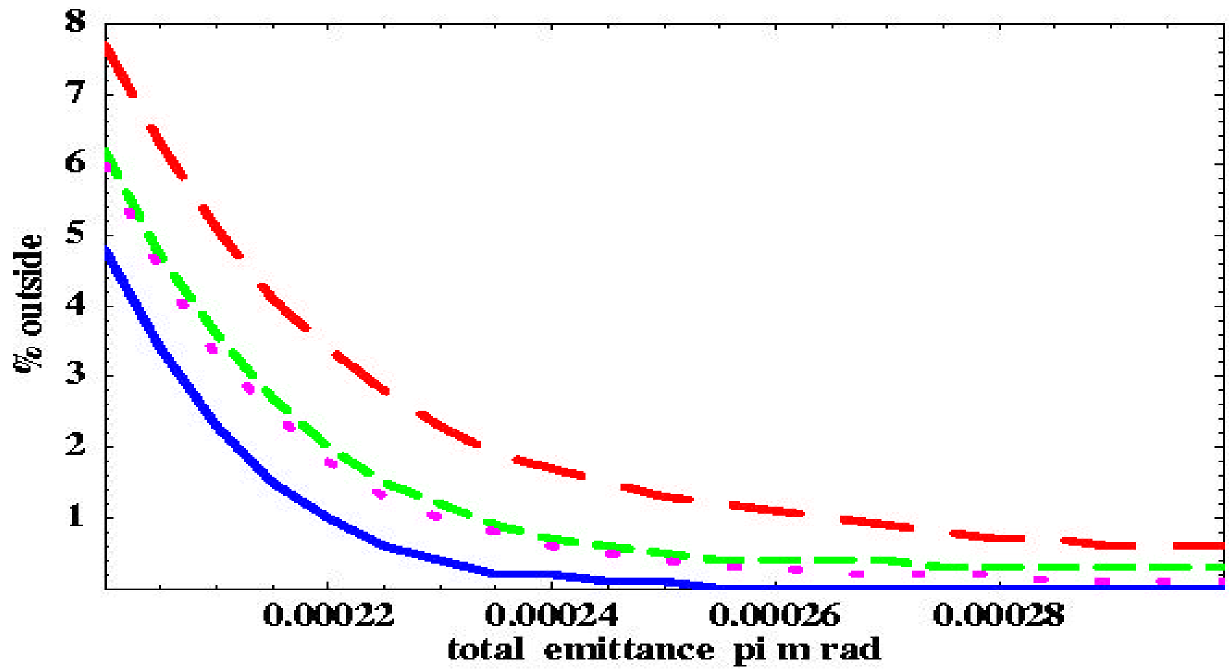


Blue – **no SC, nat. chromaticity (-7)**

Green – SC, zero chromaticity

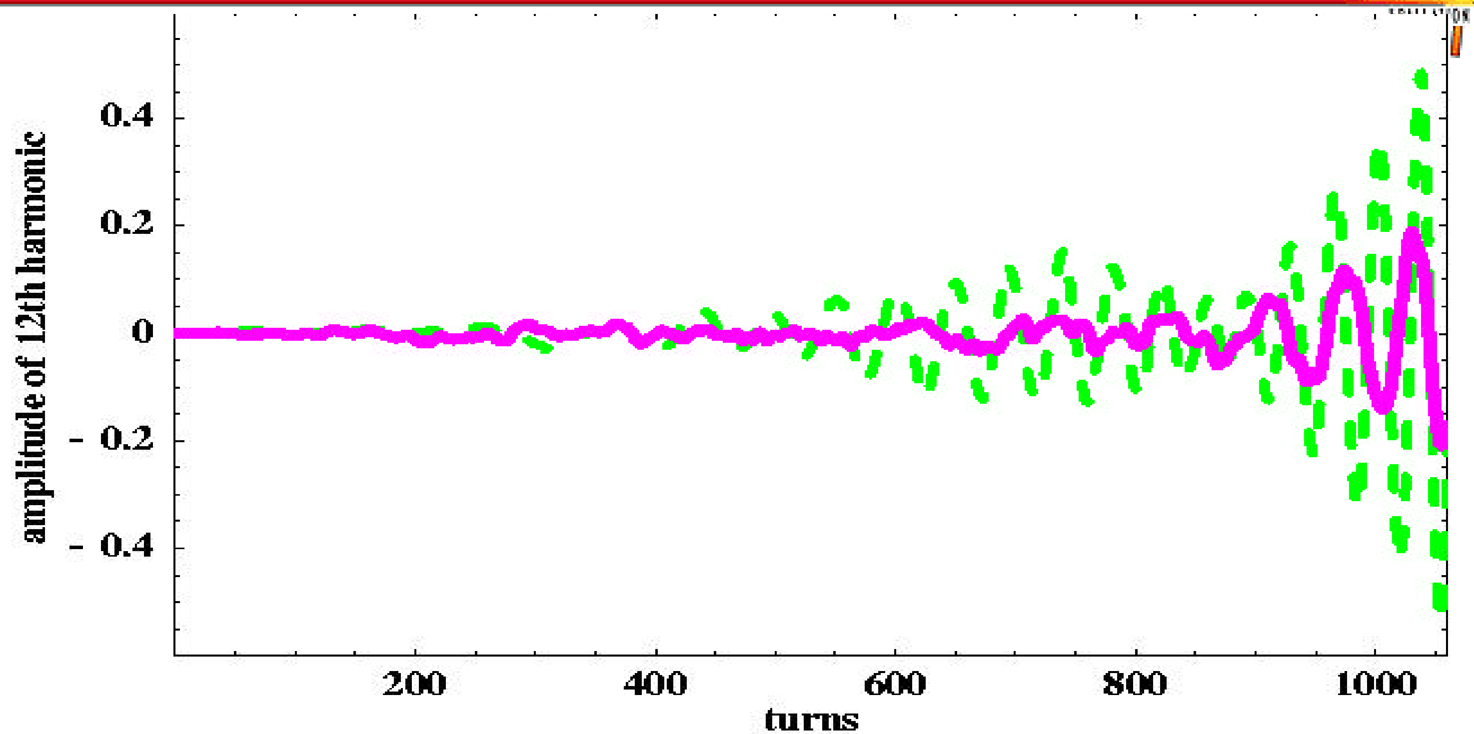
Pink – **SC, nat. chromaticity**

Resulting beam halo for N=2.0*10^14



Blue – no SC, nat. chromaticity (-7), b=11cm
Green – SC, zero chromaticity, b=11cm
Pink – SC, nat. chromaticity, b=11cm
Red - SC, zero chromaticity, b=20 cm

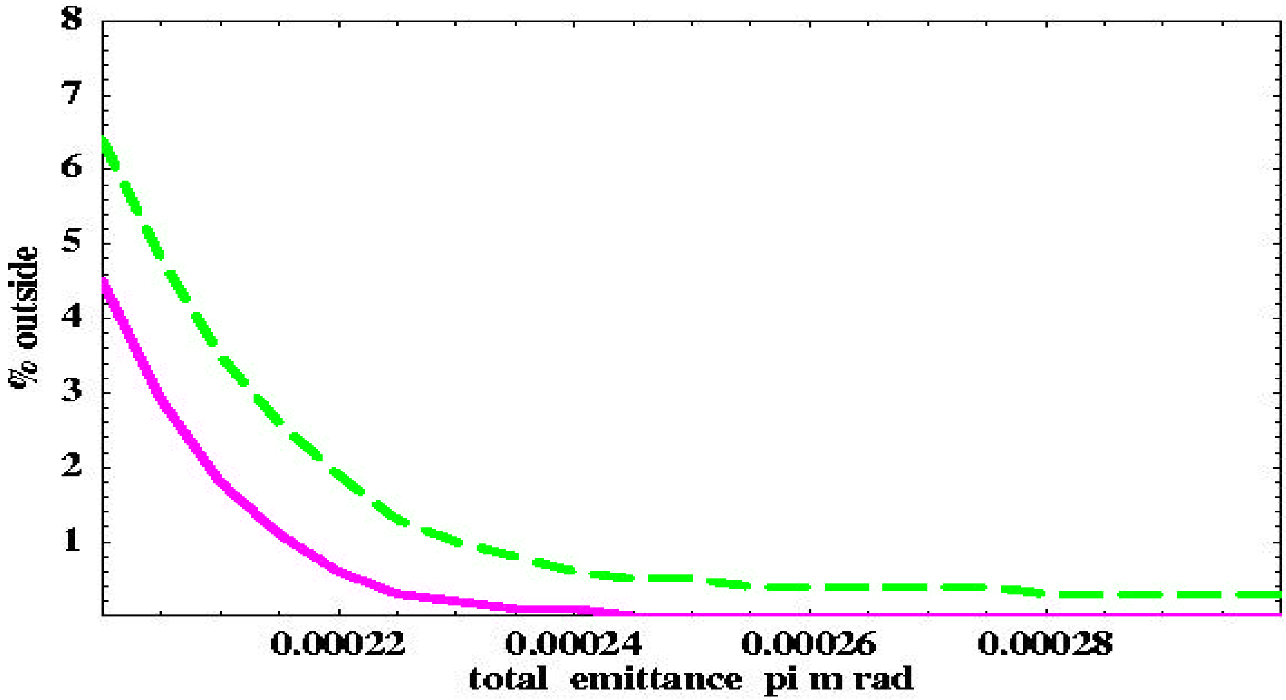
N=1.5 *10^14 at the end of accumulation



Green – SC, zero chromaticity

Pink - SC, nat. chromaticity (-7)

Resulting beam halo for N=1.5*10^14



Green – SC, zero chromaticity

Pink - SC, nat. chromaticity (-7)

Intensity limitation

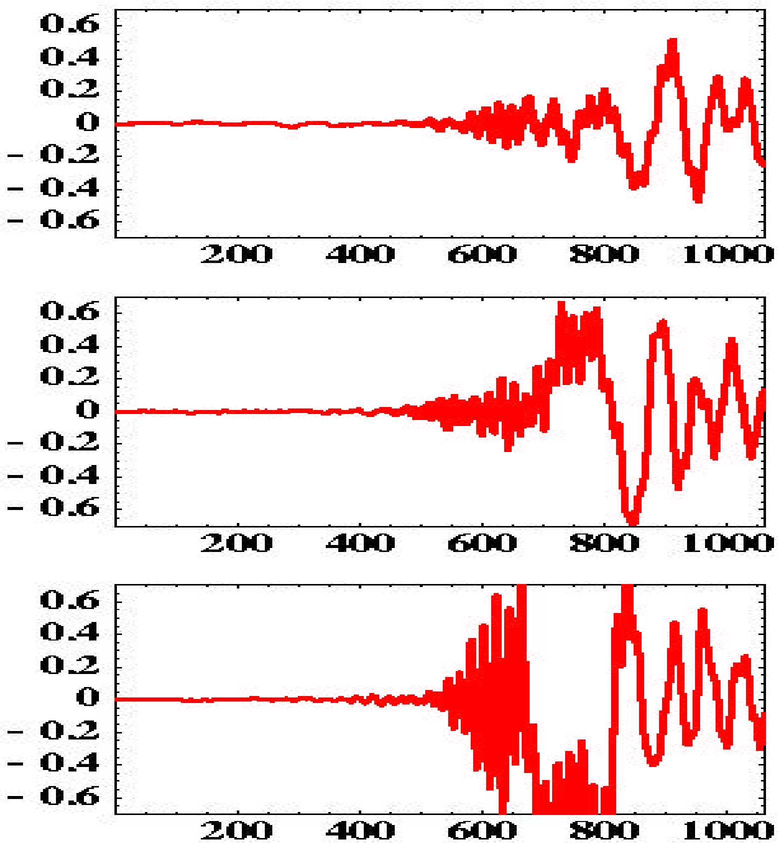
- N=2.0*10^14 – Unstable, using natural chromaticity is not enough, additional damping with non-linear spread due to octupoles but most likely unsufficient for this intensity. Needs feedback system or minimization of impedance.
- N=1.5*10^14 – Unstable with zero chromaticity. Marginally stable with natural chromaticity. Additional small damping with octupoles can help. Feedback system is not required (when working with nat. chromaticity) but it is recommended.
- N=1.0*10^14 – Stable with natural chromaticity. With zero chromaticity no significant halo is observed by the end of accumulation.

25 Om vs Open termination

- **Open termination: Large impedance around 30 MHz where Landau damping may be effective. Very small impedance till 10 MHz where Landau damping is not effective.**
- **25 Om termination – removed pick around 30 MHz but introduced much stronger impedance at low frequencies with pick around 5 MHz.**

With SC , open termination case is more unstable.

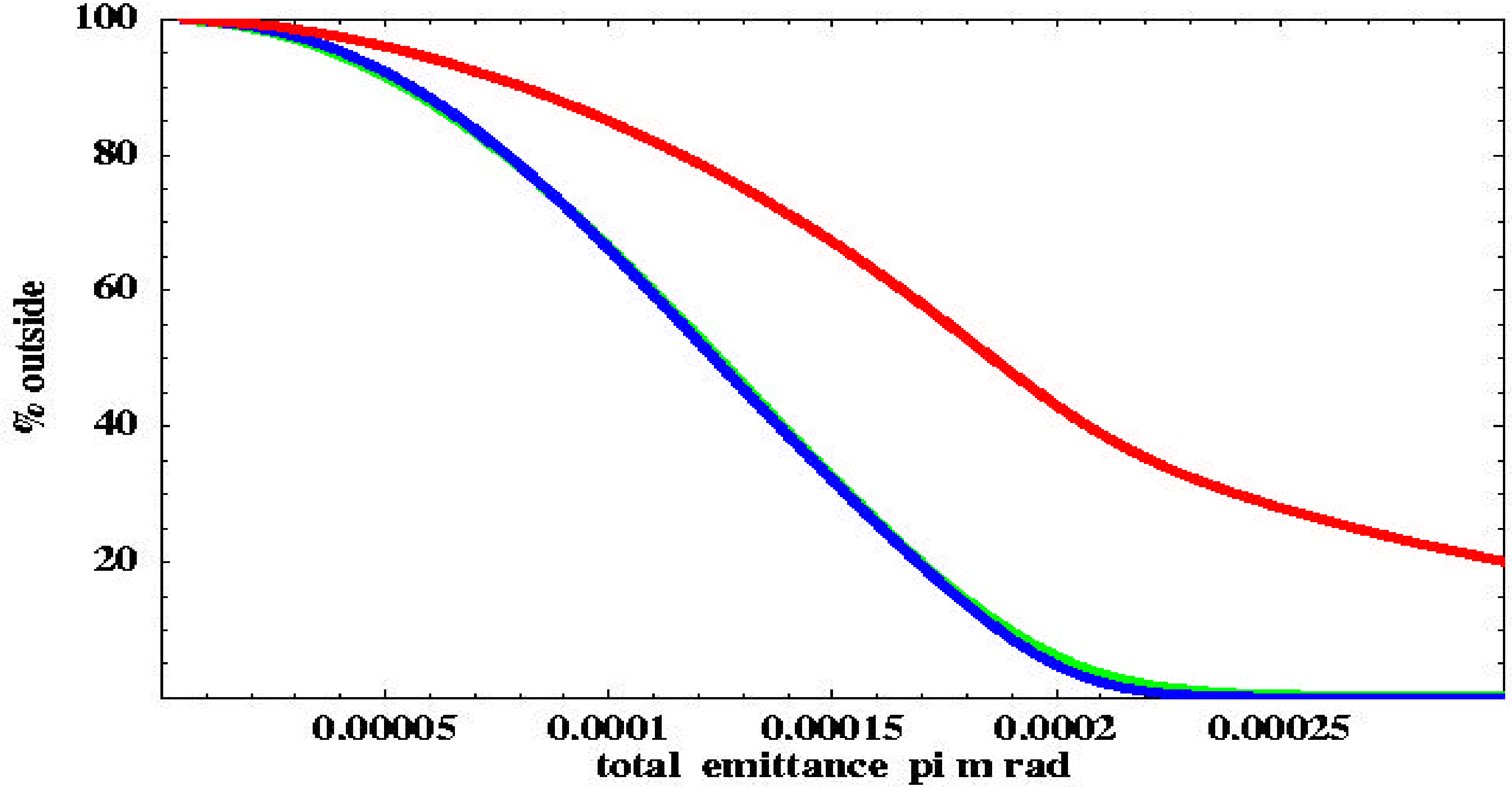
Instability growth due to open termination impedance (6, 18 and 22 MHz)



N=2*10^14, SC, natural chromaticity

Strong instability at high-frequencies

Beam halo due to open termination impedance



Low frequencies and space-charge stabilization

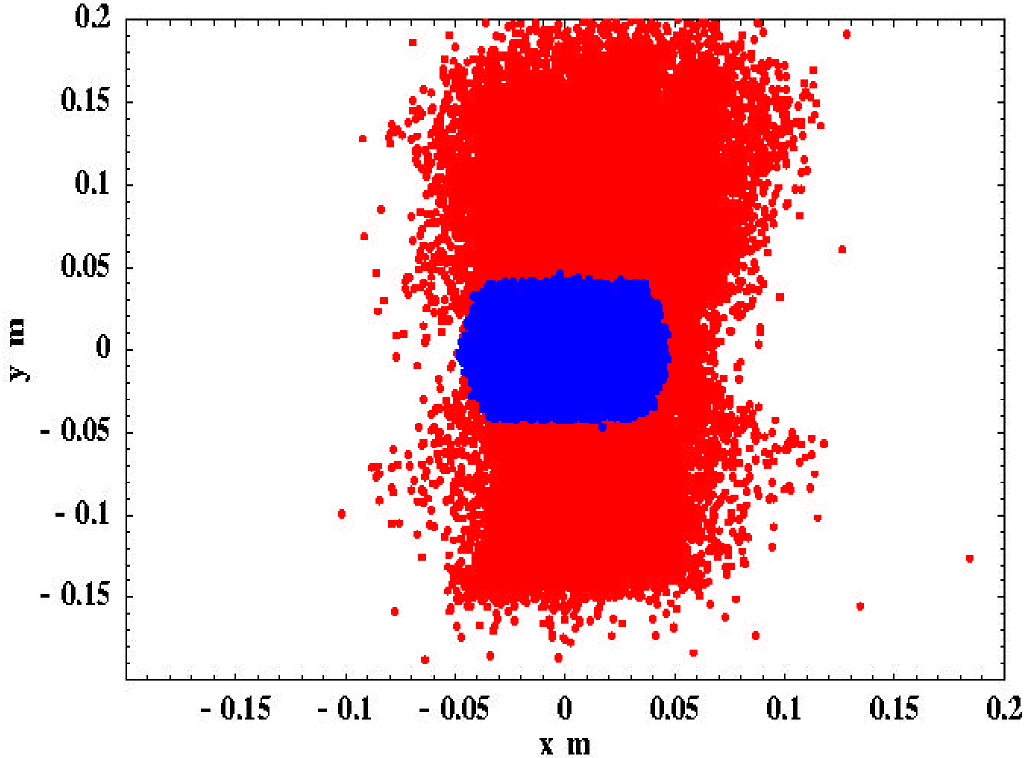
- 25 Om termination case has large impedance at very low frequencies (1-2 MHz). If we set chromaticity to zero then dp/p spread is not enough to damp unstable low-frequency harmonics. For these harmonics s[ace-charge has stabilizing effect due to the tune spread associated with b/a variation along the bunch.
- Analytic estimates shows that without SC and zero chr. 2*10^14 beam is approximately factor of 2 above the threshold, with stable beam below 0.8*10^14.
- Simulation: (No space charge, zero chromaticity)

  2.0*10^14 – unstable

  1.5*10^14 –unstable

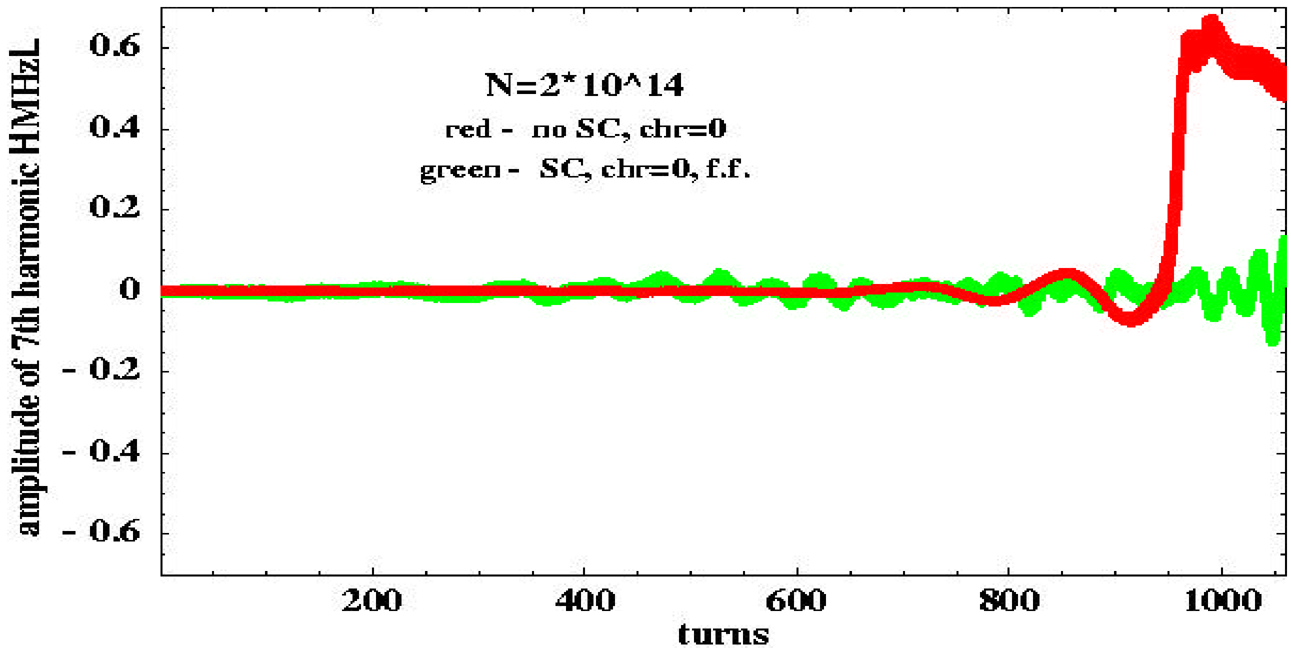
  0.8*10^14 - stable

Stable case vs the case without stabilization



red – zero chromaticity, no space-charge – no stabilization at low frequency – complete blow-up of beam by the end of accumulation (2*10^14).

Instability below 5MHz (2*10^14)



1. No SC, chromaticity=0 –unstable at very low freq. 1-6MHz
2. SC, chr0maticity=0, fringe fields, - stable at low freq. Because of space charge longitudinal detuning, unstable for frequencies above 5MHz.

b/a dependence and stabilization (b - pipe raius, a- beam radius)

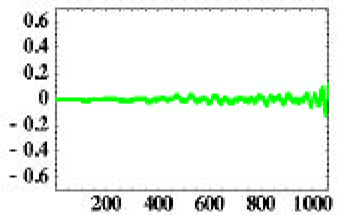
- b/a variation along the bunch introduces effective tune spread (due to longitudinal current density) and thus plays stabilizing role.
- Making ratio b/a larger decreases stabilization and makes beam more unstable.
- If b/a is too small one gets into the region where image effects play the dominant role – "quadrupole" effect.

Instability for different b/a ratio

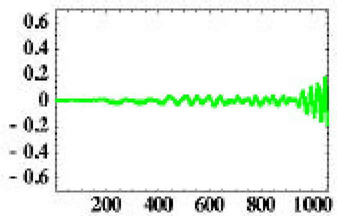
SNS
SPALLATION NEUTRON SOURCE

b=11 cm

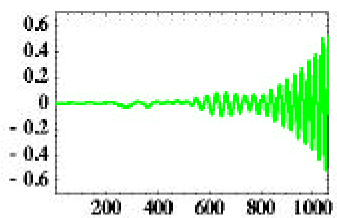
1MHz



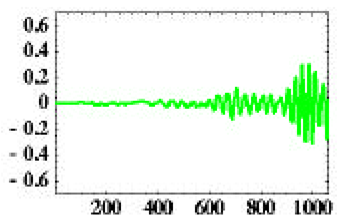
2MHz



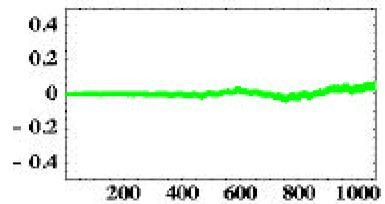
6MHz



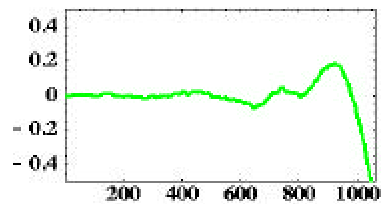
9MHz



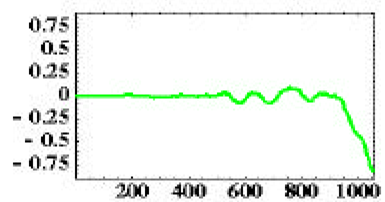
b=20cm



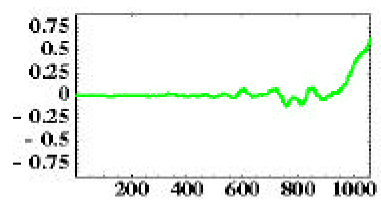
1MHz



6MHz



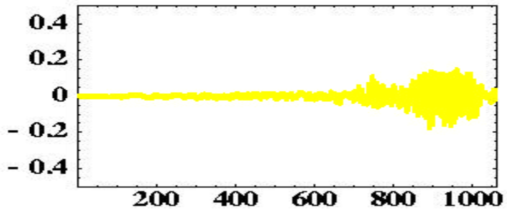
9MHz



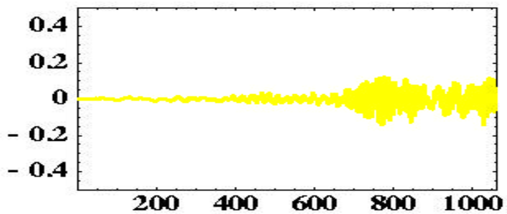
11MHz

b=6cm (with beam radius “a” approaching 4cm by the end of accumulation)

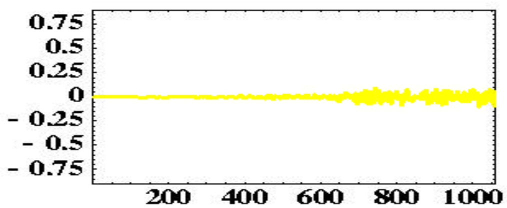
1MHz



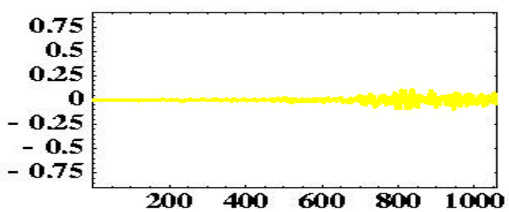
6MHz



9MHz



11MHz



Beam halo for different b/a ratio